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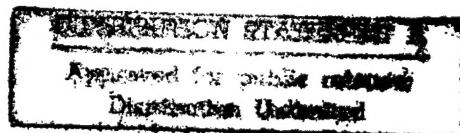
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17 January 1985

# West Europe Report

SCIENCE AND TECHNOLOGY  
RESEARCH IN ROBOTICS,  
SENSORS, OPTICS IN FRG

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17 January 1985

WEST EUROPE REPORT  
SCIENCE AND TECHNOLOGY  
RESEARCH IN ROBOTICS, SENSORS, OPTICS IN FRG

Stockholm UTLANDS RAPPORT in Swedish No 8401, Sep 84 pp 1-53

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## FACTORY AUTOMATION

### PRESENT, FUTURE RESEARCH IN ROBOTICS, SENSORS, OPTICS IN FRG

#### Situation Overview

Stockholm UTLANDS RAPPORT in Swedish No 8401, Sep 84 pp 1-2

##### [Text] 1. Introduction

Industrial robots have been used since the early 1970's in the FRG. A pioneer among the users was the firm of Daimler-Benz, which as early as 1971 utilized welding robots for spot welding in the production of S-class Mercedes cars in Sindelfingen (1).

Since then the number of application areas and the number of industrial robots have increased strongly. In the last two years alone the total number has doubled to more than 4,800 (at the turn of the year 1983/84), (2). Most of the industrial robots have been installed at the major companies. Only one out of nine robots is installed in medium-sized and small companies, (3).

According to VDI [Association of German Engineers] Guidelines "Montage- und Handhabungstechnik" [Assembly and Handling Technique], the FRG definition of industrial robots is, briefly: "By industrial robots is meant universally utilizable movement automations with more than three degrees of freedom, whose sequence of movements can be freely programmed and controlled by sensors."

Presently, the largest manufacturer as well as user of industrial robots in the FRG is the Volkswagen Works in Wolfsburg. On the whole, this production satisfies the domestic demand, (4).

Increased competition mainly from Japan and the United States, as well as high labor costs have forced the increased automation in FRG industry. In many sectors, however, the introduction of industrial robots is taking place relatively slowly.

The concept of a "robot" has an ugly sound to many workers, at the same time as high unemployment increases the difficulties of introduction. Compared to Japan or Sweden, for example, the attitude here is more negative, (5). One justification for introducing them is the companies' opportunities to compete in the export market through greater automation. However, for heavy, dirty, noisy and monotonous work the use of robots is completely acceptable.

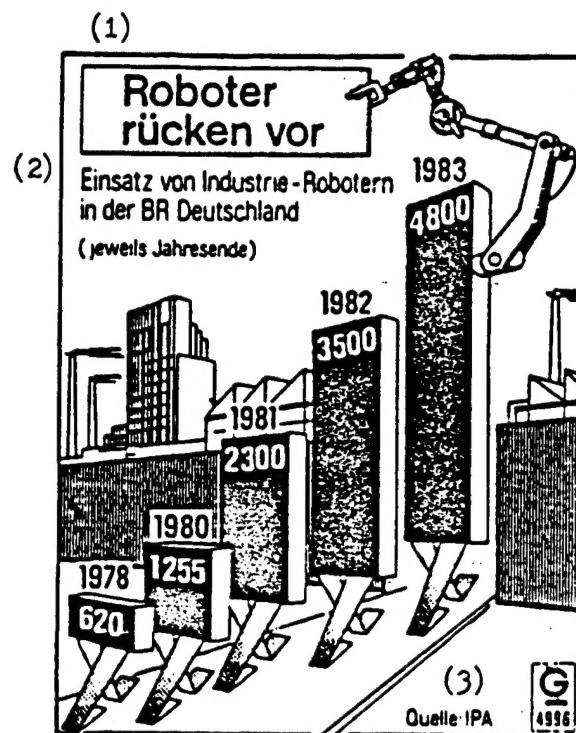


Figure 2.1. The development of the number of industrial robots in the FRG

Key:

1. Robots advance
2. Use of industrial robots in the FRG (at the end of each year)
3. Source: IPA

In the FRG, as in many other Western nations, the largest future market for industrial robots is expected to lie in the field of automatic assembly (6).

Most FRG robot manufacturers are now converting in order to meet the increased demand in this sector. The development of the sensors required for this has intensified, know-how is being purchased and a great deal of effort expended on improving the software.

Nowadays attempts are made as early as the construction stage to adapt the products to automatic processing. In this manner effective utilization of robots is made possible.

The trend among industrial companies is higher turnover but with fewer employees. This results in greater labor market problems, which one attempts to solve through, for example, increased retraining of the personnel, with more or less successful results. The Federal Government also supports various research projects, in which the effects of the computerization of industry are being studied.

## Current Situation

Stockholm UTLANDS RAPPORT in Swedish No 8401, Sep 84 pp 3-5

### [Text] 2. The Current Situation in the FRG

At the turn of the year 1983/84 there were more than 4,800 industrial robots installed in the FRG. This is the equivalent of twice the number in 1981 and an increase during 1983 of 1,300, see Fig. 2.1, (1) and (7). It is estimated that by the end of 1984 the number of robots will have risen to over 6,000.

Most of the robots, 60 percent, are found in the automobile industry. When comparing the "robot density" of various countries, the FRG ends up in third place behind Sweden and Japan.

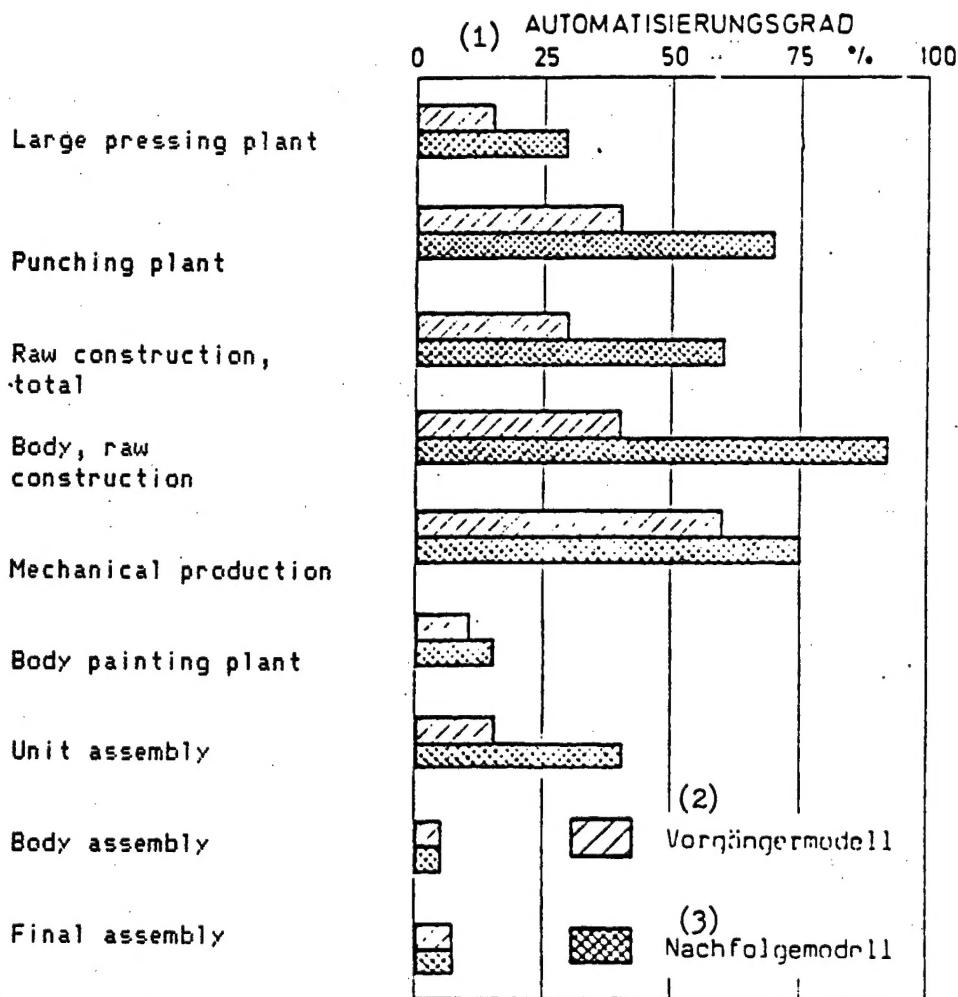


Figure 2.3 The degree of automation in automobile production at BMW  
Key: 1. Degree of automation 2. Previous model 3. Subsequent model

The pioneer among industrial robot users in the FRG is the automobile industry. However, usage among automobile manufacturers varies considerably. Fig. 2.3 shows the degree of automation in various areas at BMW (6). In particular, the low degree of automation for painting and final assembly is noted. In comparison may be mentioned that VW in Wolfsburg has automated over 25 percent of the final assembly, see section 3.2. In body manufacture the use primarily of spot welding robots is common among all automobile producers.

At Porsche the first two robots were installed in 1983. One of the robots handles engine blocks, the other is used for welding tasks. The low utilization of industrial robots depends on two things: Partly, the cars are produced in small series (about 80/day) and partly the kind of space required by the robots has not been available.

#### Applications of Robotics Technology

Stockholm UTLANDS RAPPORT in Swedish No 8401, Sep 84 pp 6-16

#### [Text] 3. Application Areas

##### 3.1 General

The use of industrial robots in various areas of the FRG, as well as the development from 1980 to 1983, is shown in Fig. 3.2 (6). Depending on whether the robots work with a tool or whether they handle a workpiece, they are divided into tool-handling or workpiece-handling robots. Tool-handling robots are completely dominant and include areas such as welding, surface coating and assembly. Workpiece-handling robots handle the processed material in pressing, forging and other machine-tool operations, stacking in warehouse systems and unloading and loading of conveyor belts.

The largest number of robots (1,560) are found in the area of spot welding. The rate of increase in this area has slowed down, however, which is due to the fact that spot welding is already a well-established technique among automobile manufacturers, in particular. It is followed by the arc welding sector (856). Here, advanced sensors are needed in order to track along the welding joint, see further under section 3.1.

In the surface-coating sector (586), robots work with spray-painting and undercoating, and to some extent glueing. Only a few spray-painting robots are of domestic manufacture.

A major problem area for the use of industrial robots is finishing (deburring and polishing). There have even been instances when new robots were dismantled again, since it was not possible to solve the problems during actual use (8). Here, the cause is indicated as lying with the sensors.

Assembly is considered an interesting future area for robotics. The number of assembly robots has doubled during 1983, but the total number is still low, about 250. Here as well, the small number is believed to be due to the lack of advanced sensors, among other things, see further under section 3.2.

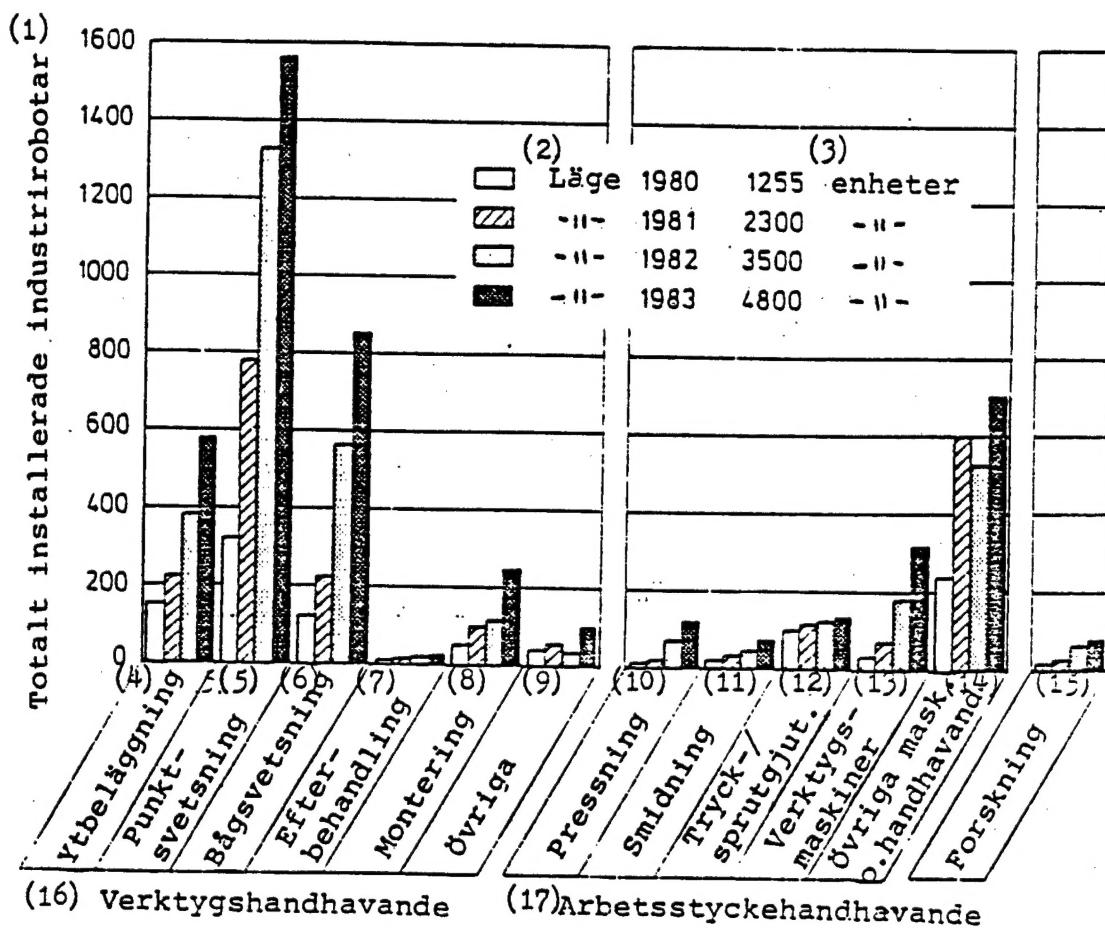


Figure 3.1 The use of industrial robots in various sectors, as well as the development 1980-1983 in the FRG.

Key:

1. Total number of robots installed	10. Pressing
2. Situation	11. Forging
3. Units	12. Pressure-/injection casting
4. Surface coating	13. Machine tools
5. Spot welding	14. Other machine and tool-handling
6. Arc welding	15. Research
7. Finishing	16. Tool-handling
8. Assembly	17. Workpiece-handling
9. Other	

In the report, emphasis has been placed on the application areas of arc welding and automatic assembly. In arc welding there is still a major future market, and the largest future market potential is regarded as being in automatic assembly.

### 3.2 Arc Welding

For several years welding has been the major application area for industrial robots. Spot welding is already a well-established area of application, while arc welding has only begun to be widespread in the last few years.

It is estimated that a well-functioning arc welding automaton can weld three to four times faster, depending on the welding method, than a welder can do manually, (9).

The basic difficulties in automating the arc welding method lie in sensing and correcting the welding joint. The development of optical sensors, among others, for this purpose takes place in the FRG principally at the Fraunhofer Institute for Information and Data Processing (IITB) in Karlsruhe, see further under section 4.1.2.

The further development of the welding robot systems has opened new areas of application in machine-building, electrotechnology and metal processing. The largest share of arc welding robots are today found in large-scale and mass-production. The flexibility of the robots is poorly utilized for this purpose; at most it is used in product exchange or construction changes. The large market lies in small and intermediate series. How can it be, then, that the major use of arc-welding robots in the FRG is for large-scale manufacture?

According to diplomate engineer H. Gzik, Fraunhofer-Institute for Production Technique and Automation (IPA) in Stuttgart, this is due to the following, among other things:

- Arc-welding robots are still relatively expensive for smaller companies, in particular the necessary peripheral equipment which is extra.
- The costs of the necessary fixtures can become considerable.
- Many advantages are difficult to quantify, i.e. in an investment calculation the value of the following, for instance, may be misjudged:
  - The reproducibility of the quality of the welded joint
  - Less material waste due to more even quality
  - Improvement in working environment for the welders
  - Potential construction change for welding more suitable for robots
- For small and intermediate firms the work and planning of an automated industrial robot system implies new, unknown areas, since they lack the required know-how.

Similar problems are also found in the field of automated assembly, see next section.

At BMW in Munich arc welding robots are used in conjunction with special welding machines equipped with several rods (9). These special machines were the beginnings of welding automation and today work hand in hand, so to speak, with the robots.

### 3.3 Automatic Assembly

In the FRG 1.2 million industrial workers, that is one-sixth of all industrial workers, work in the area of assembly. In the automobile industry as many as 40 percent of the employees are involved in assembly work (10).

High labor costs, demands for competitive products and even production are forcing increased rationalization and automation in the assembly sector.

At the end of 1983 only 5 percent of all the installed industrial robots in the FRG worked with assembly tasks. However, the total number of assembly robots doubled in 1983 to over 250.

According to Dr-Eng M. Schweitzer, who heads the Fraunhofer Institute for Production Technique and Automation in Stuttgart, an avalanche-like increase in the number of assembly robots is anticipated as soon as the peripheral problems are solved. The periphery, that is to say the equipment around an assembly robot, includes material handling, control systems and advanced sensors.

A major effort is under way on various vision systems, see section 4.1.2.

Which are the causes, then, which have slowed the introduction of assembly robots? According to Prof Dr-Eng J. Milberg, Institute for Machine Tools and Operational Sciences at the Technical University of Munich (TU-Munich), it is possible to point to the following things, among others:

--Assembly is a complicated field, in which several entirely different parts must be mounted with sometimes unconventional methods.

--During the construction of a product, most of the work is usually expended on making the product "production-friendly" instead of making the product "assembly-friendly" as well.

--The demands imposed on the handling equipment in automatic assembly are met technically and economically only during continued development of control systems and sensors.

In automatic assembly it is essential that the product is "suitable for assembly" by a robot. By that is meant, among other things, that there is only a small number of parts to be assembled. One example is the car door suitable for assembly, which was developed at TU Munich.

Another procedure developed in a project at TU Munich in cooperation with several robot manufacturers is automatic mounting of weather strips and windows on automobile doors (6).

The assembly system has developed by means of different robots and driverless material-handling trolleys. A special mechanism for the robot arm is used for mounting the weather-strips. The rollers of the mechanism are used both for

pressing in and guiding the rubber strip. Problems occurring in this area were due to, among other things, the elasticity of the rubber during mounting.

The supply of screws for the various screw moments takes place through plastic hoses and by means of compressed air.

The major user of assembly robots is Volkswagen Works in Wolfsburg. Final assembly of the new Golf model (II) takes place in the new assembly hall, Hall 54. A large number of parts are mounted with the help of about 40 assembly robots and many pieces of flexible handling equipment, see Fig. 3.6, completely without the help of humans (11).

The degree of automation in assembly has been raised from 5 to 25 percent, which is considerably higher than in the rest of the automobile industry. The degree of automation is to be raised to 33 percent by 1990.

The total investment for the new hall amounts to over DM 550 million. The cost of the automation itself was over DM 220 million. In comparison with assembly of the previous model of the Golf, Hall 54 means a total saving of about 1,000 employees. Some of these are now working with supervisory duties instead, while the remainder have been transferred to other sections of the VW concern.

More than 2,400 cars are manufactured per day in the new hall. With two shifts this means a new car every 16 seconds. This placed very high demands on the planning of the hall. For instance, the number of body variants was reduced. The previous Golf model was manufactured in 3,600 different raw bodies, while the new model has only four-, two- or four-door [sic] variants, with or without sunroof (12).

In Fig. 3.7 the battery is put into place, another robot screws it tight at the next station. By keeping the body in a fixed position, the reference points are the same for each type of car, but the battery types vary for the various models.

In Figure 3.8 a robot is putting the spare tire in its place. The placement is done with exact precision, the correct spare tire having been chosen for each car model.

More than 300 screws are to be put into place in each car. Supplying screws was long a major problem. It was solved in this area as well by transporting the screws in plastic hoses by means of compressed air, sometimes as far as 30 meters. It became necessary to develop a new type of screw that can take this treatment.

The major part of the assembly work for the new Golf model is still done manually, however. According to engineers at VW, the robots will never be able completely to replace humans in assembly work. Today, the robots primarily carry out heavier assembly work.

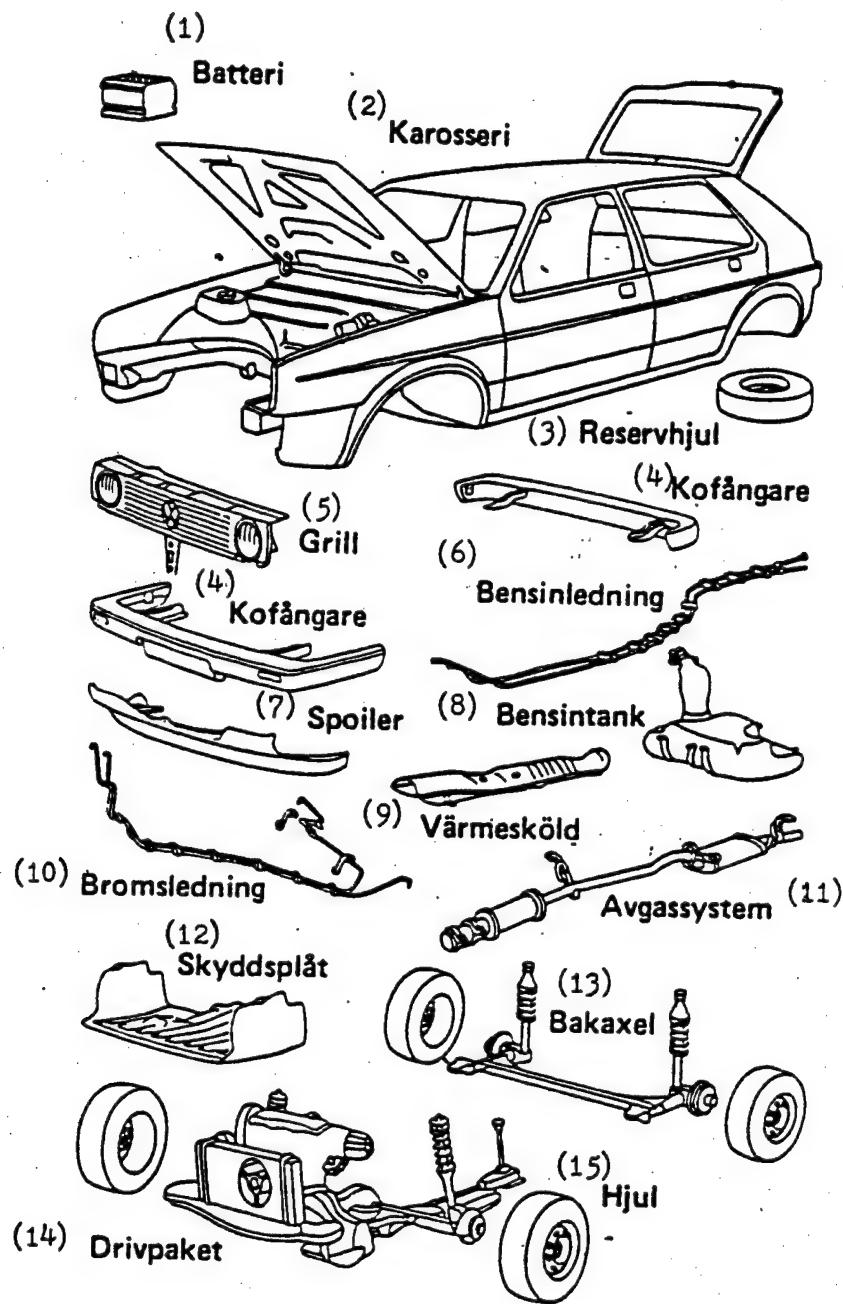


Figure 3.6. The parts shown here for the new Golf model are assembled totally without human help.

Key:	1. Battery	5. Grill	9. Heat shield	13. Rear axle
	2. Body	6. Fuel line	10. Brake line	14. Drive train
	3. Spare tire	7. Spoiler	11. Exhaust system	15. Wheel
	4. Bumper	8. Gas tank	12. Protective plate	

## Research and Development

Stockholm UTLANDS RAPPORT in Swedish No 8401, Sep 84 pp 17-32

### [Text] 4.1 Distribution and Support

Research and development in West German industrial robot technology is under way in several different areas at state and private research institutes, universities and institutes of technology, as well as in industry. Intense cooperation also takes place between these various organs.

The Federal Ministry for Research and Technology (BMFT) distributes direct and indirect state financial support for various institutes and projects, (13) and (14). However, the BMFT's support has partly been concentrated to a few Fraunhofer institutes (FhG) for applied research.

The leading institution in robot research is the Fraunhofer Institute for Production and Automation (IPA) in Stuttgart. Of a total of 160 employees, over 40 persons work with robot technology and sensors, and 60 percent of the activity is based on government funding, the remainder consisting of commissioned research. The focal point of the research lies in the areas of sensors, assembly techniques, layout planning, robot-environment interconnection and simulation of total systems.

The Fraunhofer Institute for Production Facilities and Construction Technique (IPK) in Berlin also undertakes extensive robot research. Of the total of 150 employees more than 25 persons work in robot technology, mainly in the field of system development. More than three-fourths of IPK's budget consists of commission income, the rest is state funding. The focus of the research is on the software side, meaning robot programming. Work is also done on peripheral equipment problems and optical sensors. IPK has participated in the development of Siemens control system Robotcontrol, among other projects.

The Fraunhofer Institute for Information and Data Processing (IITB) in Karlsruhe places its emphasis on the field of sensors. Here, more than 100 of the total 240 employees work with optical systems. The principal activities are basic research and new development.

At the Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt [German Research and Development Institute for Aeronautics and Astronautics] (DFVLR) in Oberpfaffenhofen the emphasis is on research in space systems. More than 20 persons of the 800 employees work directly with sensor development for robots. Basic research and method development are the main activities here.

Further, applied research in the robot field takes place at the Fraunhofer Institute for Transportation Technique and Product Distribution in Dortmund, as well as at the Fraunhofer Institute for Production Technology in Aachen.

In order to increase West German Know-how in the engineering industry, the Federal Government has instituted a 4-year (1984-87) support program for production technology. The purpose of the program is to accelerate the development and application of modern information technology in production. The total budget for the program is DM 530 million, distributed over the years according to Table 4.1. The fifth year (1988) is intended for financial liquidations.

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Table 4.1 Budget for the Support Program in Production Technique

	1984	1985	1986	1987	1988
million DM	70	125	130	135	70
Total: DM 530 million					

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DM 350 million of the total amount have been set aside for indirect specific measures. These specific measures consist of:

- A: Development and application of computer-aided construction and production aids (CAD/CAM)
- B: Development and application of industrial robots and flexible handling equipment

In area A applicants can receive a maximum of DM 400,000, in area B a maximum of DM 800,000. It is not possible to receive funding from both A and B, however.

By April 1984 1,080 applications had been received. Of these, more than 940 applications were in the CAD/CAM area and more than 140 for the development of industrial robots. Due to the great demand, Research Minister Riesenhuber then decided to increase the indirect amount from DM 350 million to 450 million, that is to say an increase of the support program by DM 100 million.

As early as during 1980-1983 there was an equivalent support program for the field of production technique. During these years 270 different companies with a total of about 400 projects were able to split DM 164 million. Eighty percent of the support went to small and medium-sized companies.

An appropriation exists for the development of control and electronics in the production area (robots, handling equipment, etc.) in the machine area within

the program for microelectronics. The appropriation for 1982-84 is over DM 90 million.

In conclusion may be said that there is a good supply of government grants and that in recent years they have also increased markedly.

Very close and extensive cooperation with research institutes and colleges is taking place for research and development in the industry. IPK in Berlin is doing commissioned research for VW's robots, for example. Furthermore, Institut fuer Werkzeugmaschinen (Institute for Machine Tools) at TU-Munich cooperates with several robot manufacturers for the development of systems for automatic door mounting, among other things, see also section 3.2.

At IPA in Stuttgart a mobile robot system has been developed in cooperation with the firm of Jungheinrich in Hamburg (15). The mobile robot consists of an inductively controlled material-handling trolley with an industrial robot mounted on it. On the trolley is also an automatically movable loading pallet. The system is utilized for changing tools at various processing centers. One of the advantages of the mobile system is that it is possible to achieve a greater degree of utilization of the robot. At each work station the trolley is mechanically steadied in order for the necessary positioning accuracy to be achieved. The energy requirement of the trolley is satisfied by automatic charging of the batteries through fixed contact installations.

#### 4.2 Sensors

At the same rate as the application of industrial robots is increasing, the need for various types of sensors has also grown. The use of semiconductor technology yields interesting and new application areas for the sensors of the future. The task of the sensor is to measure or detect a physical magnitude via a signal, usually an electric one.

Two different sensor systems are needed for an industrial robot, one internal and one external. An internal system is required in order to control the robot's own condition (position, speed, moment, voltage, current etc.). Beyond that, an external system is needed for reading the environment (distance, position, orientation, speed, classification of objects, etc.).

It is believed that the development and spreading use of industrial robots is being slowed due to the lack of advanced sensors. The need is particularly great for sorting, testing and control duties as well as final processing and assembly tasks. Intense research and development is under way in the sensor field in the FRG (17).

The major part of the research is taking place at the major research institutes (principally Fraunhofer, DFVLR and Battelle), as well as in industry (Siemens, Bosch and BBC, among others).

The following two sections deal first with tactile/mechanical and remote sensors and then with optical vision systems. This selection simultaneously represents examples of the focal points of West German sensor research.

#### 4.2.1 Tactile/Mechanical and Remote Sensors

In the field of remote (tactile) sensors, research is primarily done in the force/torque area. In particular during grinding, polishing, positioning and automatic assembly it is essential that correct force and torque are achieved.

A tactile gripping tool has been developed at the Fraunhofer Institute (IPA) in Stuttgart. The tool in Fig. 4.3 is described as MTGS (Modular Tactile Gripping Sensor System) and consists of an aluminum gripping device with a strain transducer.

The gripping claw can be used for tasks such as handling sensitive plastic details, assembly in a magnetically disturbed environments or handling of rotation-symmetrical details. The measurement range is between 0 and 35 N.

At the DFVLR research institute in Oberpfaffenhofen work has been under way for several years on the development of force/moment sensors, which are to provide the robot with human "feel."

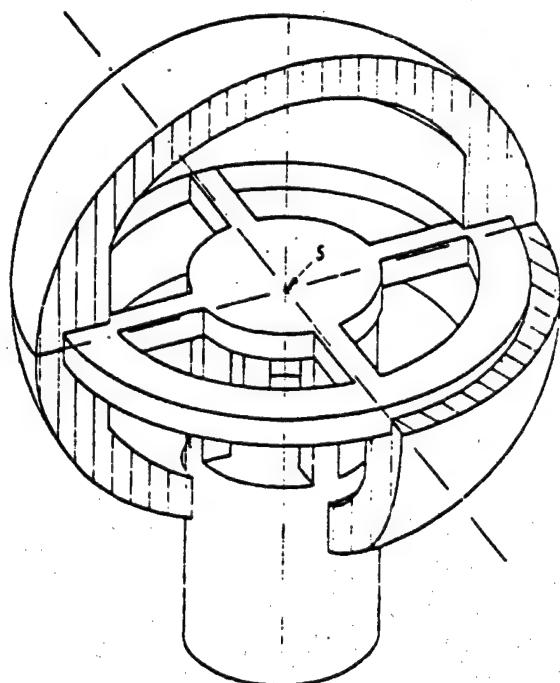


Fig. 4.4 Ball with six-dimensional force/torque sensor developed at DFVLR, Oberpfaffenhofen

One of the novelties from DFVLR in the sensor field is a six-dimensional (three forces, three torques) force/torque sensor, a so-called sensor ball, see Fig. 4.4. This sensor consists of a base ring, from which four spokes radiate toward a central core. The core is then connected by four supports to a lower core. If forces or torques occur between the upper and lower cores, form changes take place in the spokes or in the supports. These changes, in turn, are measured by eight strain transducers (DMS) mounted in pairs, (16) and (18).

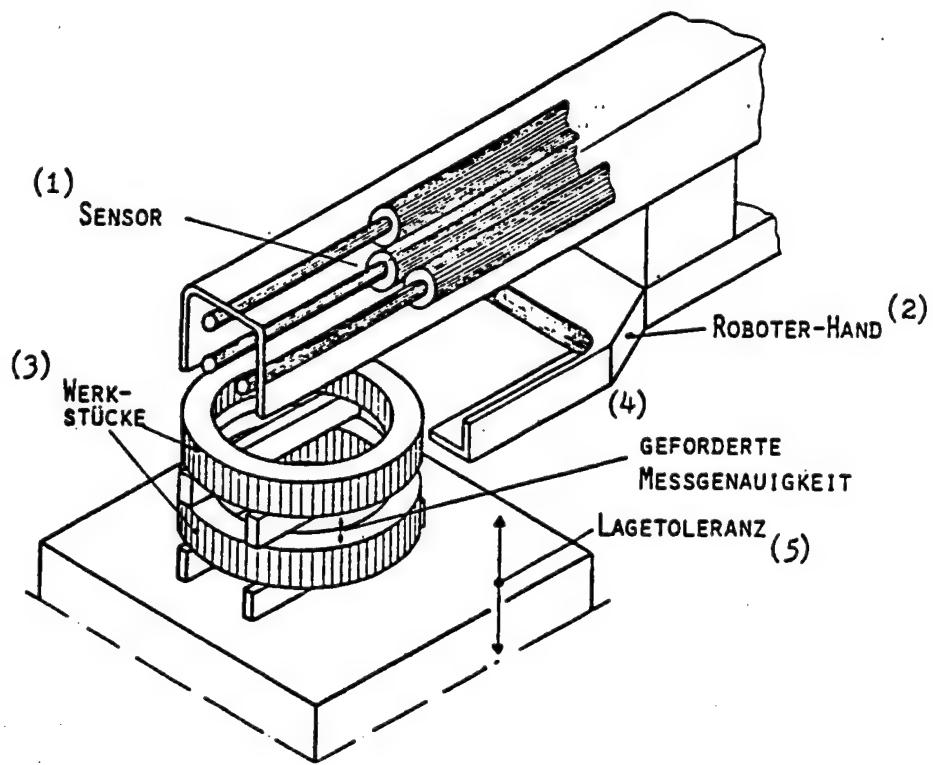


Figure 4.5 Heat resistant position sensor (D-field technology) developed at the Fraunhofer Institute in Freiburg

Key:

1. Sensor
2. Robot arm
3. Work pieces
4. Required measurement accuracy
5. Position tolerance

The sensor ball is eminently suitable for, among other things, so-called teach-in methods for programming the movements and force/torque of the robots in all positions. This is particularly applicable to assembly, grinding and screwing.

At the Fraunhofer Institute for Physical Measurement Technology in Freiburg a heat-resistant position sensor has been developed. The sensor, see Fig. 4.5, can be used for supervising tool wear, distance measurement and following contours (for example in welding). The application temperature is upwards of 1000 °C for measuring the distance to arbitrary material. The sensor consists of three electrodes mounted in a U-profile. Two of the electrodes generate an electric field, the potential of which is determined at a specific spot by the third electrode. When an object approaches the electric field, the changes in potential which occur indicate a measure of the distance (measurement principle: D-field sensor).

#### 4.2.2 Optical Vision Systems

The greatest effort of West German sensor research is taking place for the development and improvement of optical vision systems. Robots which can "see with their own eyes" are needed for visual tests, optical measurements, positioning and detail identification.

Most vision systems in operation today consist of an advanced image processing system and a simpler video camera (18). Several West German vision systems are already on the market, the largest of which are:

Manufacturer	Systems
Siemens AG	Videomat and Optomat
Bosch AG	S.A.M.
Brown Boveri & Cie.	OMS
AEG-Telefunken	Robotronic IRS

In this section the present situation of the West German systems will be presented first, and then areas of special emphasis in research.

Fig. 4.6 shows Siemens Videomat system. The system is used for identification of objects according to form, size and position. The image is registered in the form of lines (625 lines/50 Hz).

In evaluating and identifying the image according to various criteria, object numbers and the coordinates of the points of emphasis are recorded. In this example even the correct angle for the robot's handling of the object is recorded. The system is two-dimensional.

Siemens Optomat system is used for sorting details (up to 5 per second) according to form and size. Here the image is registered with photodiode

lines (128 diodes/line). The image resolution is 128 x 128 bit, which corresponds to about 16,000 image dots.

A color identification system is also under development at Siemens. A prototype has already been demonstrated at trade fairs.

Bosch AG has developed the S.A.M. image processing system, see Fig. 4.8, in cooperation with a Fraunhofer Institute. The system is intended for identification of automobile details, for example, or for control of assembly work (black-white contrasts). The signal of the video camera is compared with a pattern stored in an image memory. The reduction of the information is necessary in order to be able to process the image in a reasonable amount of time.

At Brown Boveri & Cie (BBC) an optoelectronic measurement and sensor system (OMS) has been developed for rapid image processing. The system in Fig. 4.9 is mainly intended for optical measurement of turbine blades, for example, as well as for identification and registration of details, (19). The system is two-dimensional.

AEG-Telefunken's Robotronic IBS system (Integrated Image-Processing System) utilizes the whole gray-scale in image processing. The image memory handles 512 x 512 points; each point can receive 128 different values (from black to white). The image processing time has been reduced by using a multiprocessor system.

The Fraunhofer institutes are very active in research. A large part of the industrial research in the robot field takes place in cooperation with various Fraunhofer Institutes, but with great secrecy.

At the Fraunhofer Institute (IITB) in Karlsruhe an optical sensor has been developed, whose "eye" consists of a measuring instrument working with laser technology, see Fig. 4.10.

The system works three-dimensionally. From the sensor head a laser beam is sent toward the object to be measured, at which a so-called double-central mirror is mounted. When it is reflected two parallel beams occur, with a certain deviation. The deviation of the beams is measured in the sensor head by means of position-sensitive diodes. The position is then calculated by triangulation. Movable objects can also be measured with this method.

At IITB in Karlsruhe a three-dimensional system for following optical welding seams has also been developed. The system, see Fig. 4.11, is called PASS (Programmable Adaptive Sensor System), (9). Here, the image processing takes place over rapid special processors, whose functions are programmable. Resistance to interference is obtained by utilizing adaptive regulation, that is to say the interference is recoupled in the sensor model, after which the necessary adjustments take place automatically. A binary image of the welding seam as it is perceived during the image processing is shown in Fig. 4.12.

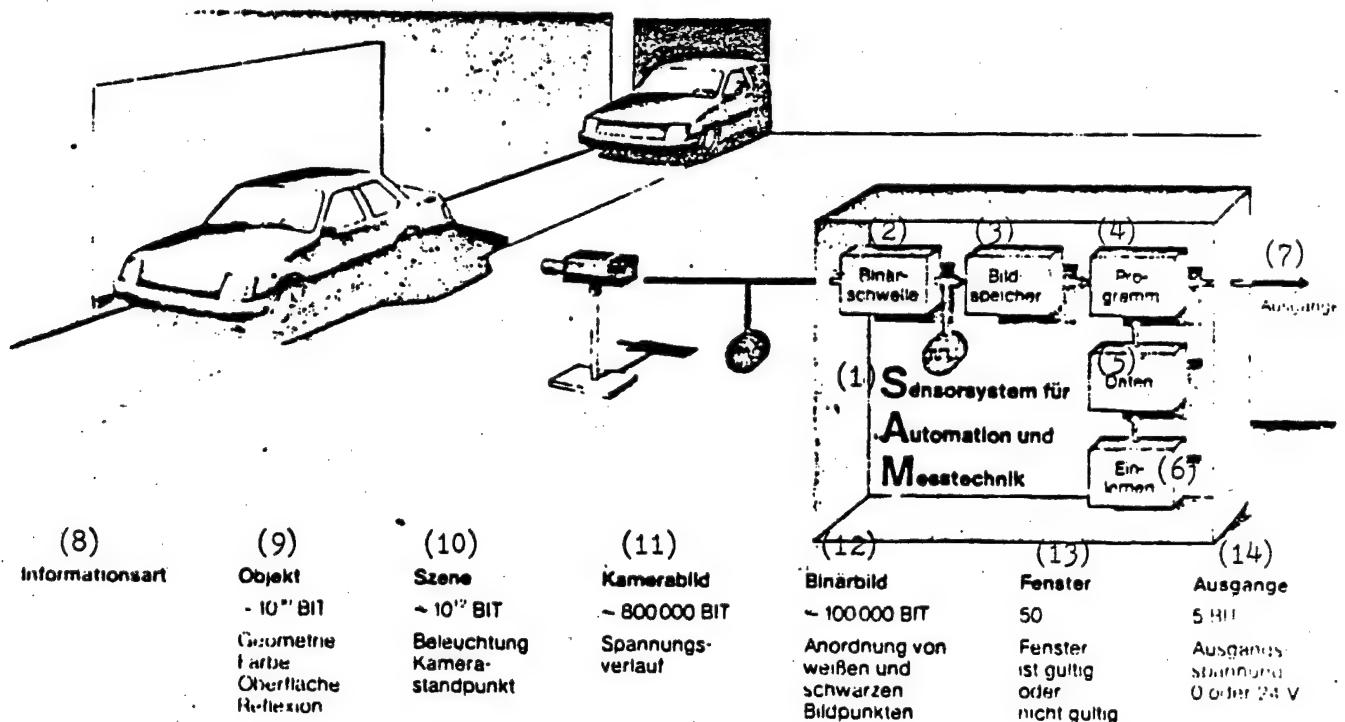


Fig. 4.8 The S.A.M. image processing system from Bosch AG

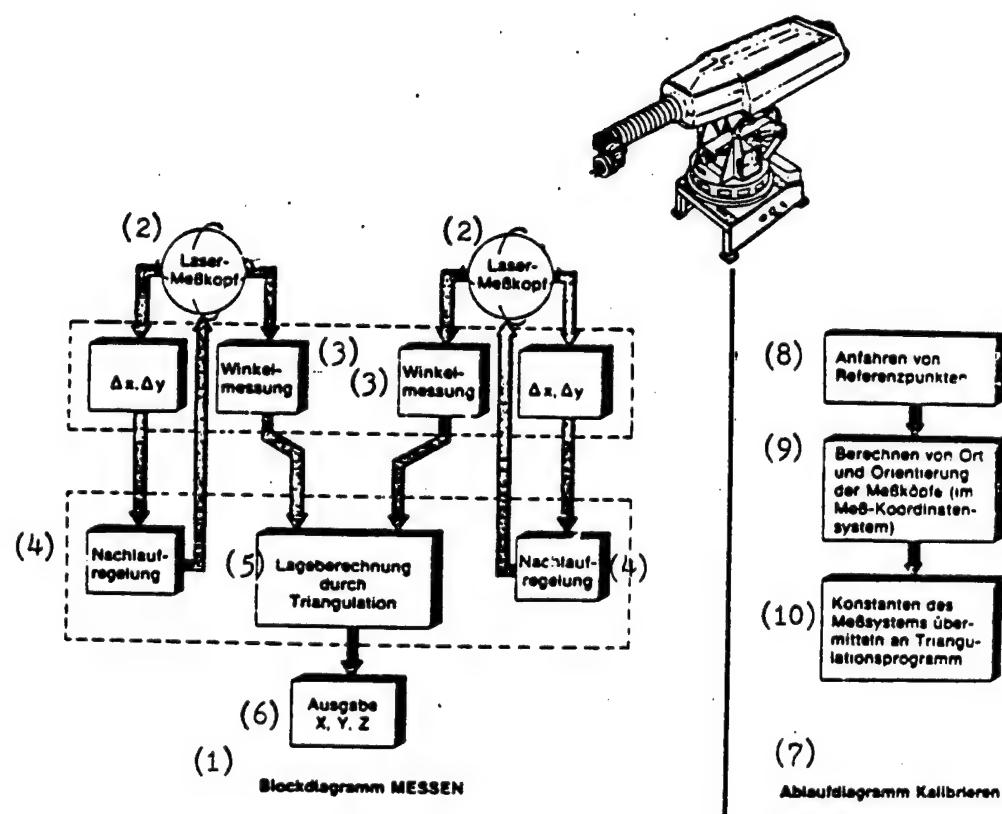
Key:

1. Sensor system for measurement technique
2. Binary threshold
3. Image storage
4. Program
5. Data
6. Instructions
7. Outputs
8. Information type
9. Object;  $\sim 10^{10}$  BIT. Geometry, color, Surface, Reflection
10. Scene;  $\sim 10^{12}$  BIT. Illumination, camera position
11. Camera picture;  $\sim 800,000$  BIT. Voltage differences
12. Binary image;  $\sim 100,000$  BIT. Arrangement of black and white image points
13. Window; 50. Window is valid or invalid.
14. Outputs; 5 BIT. Output voltage 0 or 24 V.

Fig. 4.10 3-D laser-optical positioning system developed at the Fraunhofer Institute (IITB) in Karlsruhe

Key:

1. Block diagram Measurement
2. Laser measuring head
3. Angle measurement
4. Feedback control
5. Position calculation by triangulation
6. Output X, Y, Z
7. Flow diagram, Calibration
8. Start of reference points
9. Calculation of position and orientation of the measuring heads (in the measurement coordinate system)
10. Constants of the measurement system transmitted to the triangulation program



One of the goals of the research in optical vision systems at IITB is to obtain shorter image processing times. The work is principally directed toward improving the programs. One method is to process only that part of the image which has changed since the previous sequence.

At the Fraunhofer Institute (IPK) in Berlin research is under way to transmit a certain amount of software to hardware and intermittently store images, that is to say with the objective here as well of obtaining short image processing times.

As for sensors, it might finally be mentioned that in 1984 Sweden's Technical Attachés issued a world-wide collection of foreign reports entitled "Sensors." Its emphasis is on factory-technological applications.

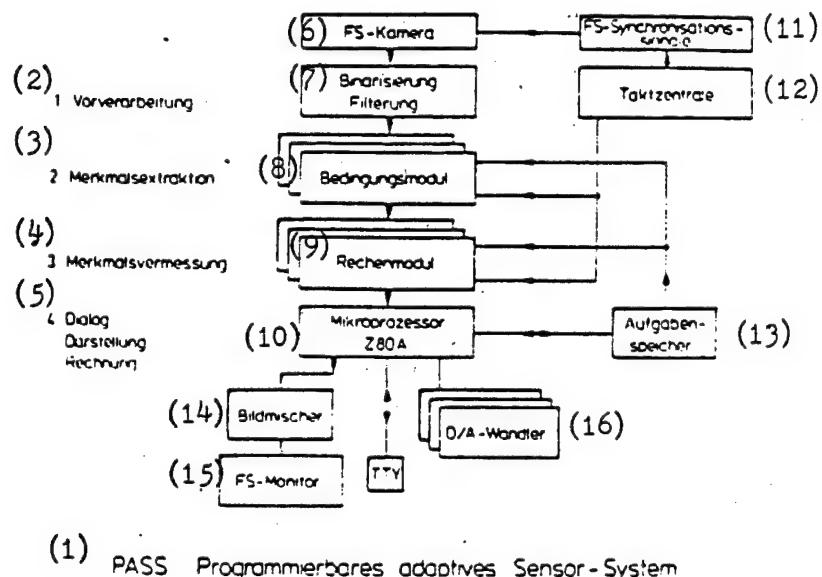


Figure 4.11 Three-dimensional optical system for following welding seams, developed at the Fraunhofer Institute (IITB) in Karlsruhe.

**Key:**

1. PASS Programmable adaptive sensor system	9. Calculation module
2. Pre-processing	10. Z80A microprocessor
3. Feature extraction	11. TV-synchronization signals
4. Feature measurement	12. Phase center
5. Dialog, Representation, Calculation	13. Task storage
6. TV-camera	14. Image mixer
7. Digitizing, filtering	15. TV monitor
8. Condition module	16. Digital/analog converter

## FRG Robotics Market

Stockholm UTLANDS RAPPORT in Swedish No 8401, Sep 84 pp 33-42

### [Text] 5. The West German Industrial Robot Market

The supply of industrial robots to the West German market is ensured by about 80 firms, over 30 of which are domestic manufacturers, (10). Over 200 different models are in the marketplace.

In 1983 the German manufacturers produced in excess of 2,000 industrial robots at a value of DM 350 million (10). This amount includes the control units as well. A total of 900 robots had been exported by 1983. Some West German manufacturers have an export share of 35 to 50 percent.

Fifty percent of the FRG market is supplied by three manufacturers. These are the Volkswagen Works in Wolfsburg, Kuka Welding Facilities + Robots Ltd. in Augsburg and ASEA-Lepper Ltd. in Friedberg, a subsidiary of Swedish ASEA.

The other manufacturers have smaller market shares and are more or less successful. Industrial robot manufacturers in the FRG can principally be connected to three different industries, where robot production represents a part of the total activity. These branches are the machine industry, the electrical industry and the automobile industry.

A large part of the manufacturers are in the machine industry, for example:

--Kuka (Keller und Knappich) Welding Facilities + Robots Ltd. in Augsburg  
--Friedrichshafen Gear Factory, Inc., Friedrichshafen

In the electric and electronics industries, these are noted, among others:

--Siemens, with its MANTEC, Fuerth, subsidiary.

Dominating as a robot manufacturer in the automobile industry is:

--Volkswagen Works in Wolfsburg

which simultaneously is the largest producer and user of industrial robots in the FRG. In 1983 alone more than 300 robots were manufactured for the company's own use. Now, a total of more than 1,200 robots have been installed, all made by VW. VW's robots cover a broad range of application from spot welding and joint welding to assembly. Fig. 5.1 shows a "stripped" VW robot crammed with mechanical elements and electrical motors. Such an automaton from Volkswagen costs about DM 180,000, to which is added service and maintenance costs of at least DM 100,000 annually (20).

VW leaders anticipate that by 1990 over 2,000 industrial robots will be in operation. Today's robots at VW have five or six degrees of freedom, work with a  $\pm 1$  mm accuracy with loads between 10 and 100 kilos (21). Only two percent of the robots work in assembly, but 65 percent do welding tasks.

At present, VW engineers are developing robots of the third generation. These are to work with two parallel arms, which save a great deal of space, among other things. A prototype is to be in operation as early as late 1984. Such a robot might function simultaneously as both jig and welder, whereby expensive fixtures become unnecessary.

A major robot manufacturer in addition to the Volkswagen Works is Kuka Welding Facilities + Robots Ltd. in Augsburg. The company's own largest area of application for industrial robots lies in welding. It has been manufacturing its own industrial robots since 1974. Before that, it was a retailer for foreign robot companies (8). The turnover in robot production was over DM 87 million in 1983.

The control equipment comes largely from Siemens (Robot Control M), but some of it is an in-house development.

As much as 90 percent of the total of 1,200 robots manufactured by Kuka were delivered to the automobile industry. Only two of these robots are installed for automatic assembly. The majority of the others are intended for spot welding. Despite the company's concentration on the automobile industry, its managing director Burhard Wollschlaeger is of the opinion that this will not cause any future problems. "In contrast to other predictions, we are convinced that the automobile industry will be the largest market in the next 10 years as well," he says. A major effort is now also being made to develop assembly robots and complete systems. Type IR 160/45 has six degrees of freedom, handles a net load of 450 N at a movement speed of 4 m/s. Reproducibility then amounts to  $\pm 0.5$  mm (22).

The firm of Reis & Co Ltd. in Obernburg, which manufactures hydraulic presses, among other things, has been making robots in series production since 1982. Today, 30 percent of the turnover consists of industrial robots. Its electrically driven V 15 robot has six degrees of freedom and handles a net load of up to 150 N. The application area for the robot is mainly in assembly and it costs about DM 100,000. Reproducibility is indicated at  $\pm 0.1$  mm. Siemens Robot Control M is used for control.

Reis is today considered the third largest West German manufacturer of industrial robots (23), after VW and Kuka. More than 300 robots have been installed, a large part of which are exported to the United States, among other countries.

Siemens subsidiary MANTEC in Erlangen/Fuerth has only begun its own production of industrial robots in the last few years. Other than that, the company has undertaken licensed manufacture of the Japanese Fujitsu-Fanuc robots. Type r3 has six degrees of freedom and handles a net load of 150 N with a speed of movement of 1.5 m/s. Reproducibility amounts to  $\pm 0.1$  mm. The type s3 expands the r3 program with a net load of up to 600 N with a movement speed of 3 m/s and a reproducibility of  $\pm 1$  mm (22).

Siemens Robot Control M is used as control unit for both models.

The Jungheinrich KG firm in Hamburg presented its model R80 at the Hanover Fair in 1983. This model has six degrees of freedom, handles a net load of up to 80 N and gives a reproducibility of  $\pm 0.2$  mm. In addition, a model R100 is marketed for a net load of up to 100 N. The welding firm of CLOOS Welding Technology in Haiger markets robots from Jungheinrich primarily for arc welding. Jungheinrich undertakes in-house development of control systems and software.

At the Ottenser Iron Works company, Hamburg, a subsidiary of the Blohm & Voss company in Kiel, industrial robots have been manufactured mainly for heavy lifting and tasks since 1981. Model D 1000 has six degrees of freedom, hydraulic operation and can cope with a net load of 1,000 N (2,000 N with reduced speed of movement). At the normal speed of movement of 2.5 m/s, reproducibility becomes 0.8 mm. Here as well Siemens Robot Control M is used for control.

The Zahnradfabrik Friedrichshafen AG [Friedrichshafen Gear Factory Inc.] has manufactured industrial robots since 1976. The handling automaten T 111 L can handle loads up to 40 kilos, has up to 5 degrees of freedom and gives a reproducibility of 1 mm.

The firm of Behr Industrial Facilities in Ingersheim has been manufacturing spray-painting robots since 1983. Behr is the first firm in the FRG to have its own domestic development and production of spray-painting robots. The Behr III robot is specially built for body painting and costs in excess of DM 300,000.

An industrial robot costing less than DM 20,000 (about 60,000 Swedish Kroner) is being marketed by the Sekuria firm in Darmstadt. The miniature robot is called Cobra RS and can handle loads up to a maximum of 1 kilo. The application areas of the robot is in the electronics industry, for control of test apparatus, packaging etc.

A more comprehensive overview of manufacturers and suppliers in the FRG, Swiss and Austrian markets is to be found in supplement 1 (24).

#### Future Prospects

Stockholm ULANDS RAPPORT in Swedish No 8401, Sep 84 pp 47-53

##### [Text] 7. Future Prospects

It is estimated that the market for industrial robots will increase strongly at least during the whole 1980's. The prognoses up to 1990 are for an increase of between 15 and 50 percent per year for both the world market and the FRG market, see Table 7.1.

By the year 2000 it is expected that the total world market will have grown to 230-330,000 industrial robots, according to a prognosis by the OECD. Up to this point in time, the demand will be met principally by new production, after which the need for replacement robots will dominate.

Table 7.1 Prognosis for production and installed industrial robots 1982-1990.  
 Source: VDMA-Professional Association MHI

Year	Country	Production		Total number of robots in use
		Number	Million DM	
1982	FRG	1,600	260	3,500
	Western Europe	2,500 <sup>x)</sup>	415 <sup>x)</sup>	9,000
	United States	.	.	9,000
	Japan	.	.	12,000
1985	FRG	3,200	600	75,000
	Western Europe	6,300 <sup>x)</sup>	1,320 <sup>x)</sup>	15,000
	United States	.	.	7,300 <sup>xx)</sup>
	Japan	.	.	13,500 <sup>xx)</sup>
1990	FRG	7,500	1,100	14,000
	Western Europe	.	.	.
	United States	.	.	31,500 <sup>xx)</sup>
	Japan	.	.	31,200 <sup>xx)</sup>

<sup>x)</sup> according to ECE

<sup>xx)</sup> according to PROCAM [expansion unknown]

What is required, then, of the robot systems of the future? The answers are many and not entirely unequivocal. A survey is given below of the future tendencies and demands in the following five areas, (30):

- Sensors
- Regulation/Control
- Programming
- CAP (Computer Aided Planning)
- Mechanical/Dynamic performance characteristics

#### Sensors

Sensors, or rather the lack of suitable ones, have often been indicated as a bottleneck for the application of robots. Today universally usable sensors are still lacking in several fields. Increased use in assembly poses great demands for development in this area. Optical vision systems, as a rule video systems, require faster image processing and cheaper systems.

The rapid development of microelectronics gives more compact, cheaper and more reliable sensors. Increased standardization of the hardware also results in lower costs. The sensor field is discussed in more detail in section 4.1.

## Regulation/Control

A trend in the field called regulation/control is increasingly to abandon so-called point-to-point control. Instead, web guides with integrated point-to-point control are being used.

This type of control is also required for the use of sensors in control.

Further, adaptive regulation systems are needed, that is to say systems which themselves modify the robot's movements according to incoming sensor signals. Accuracy during the robot's movements must also be great, at the same time as high-speed movements are taking place, sometimes with heavy loads.

Information processing during control will be further decentralized. It thus becomes possible to process control sequences in parallel, which increases the speed of the robot. A superior processor then coordinates the movements.

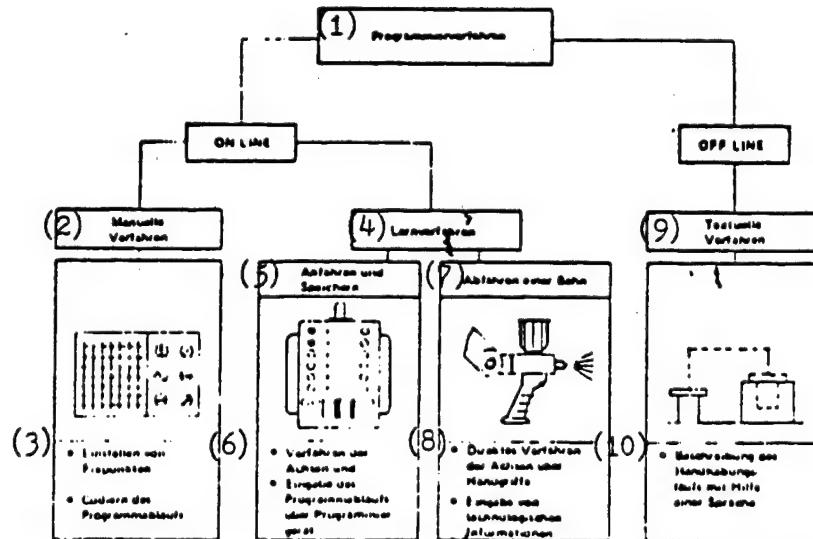
## Programming

For programming, a distinction is made between on-line and off-line, see Fig. 7.1. On-line programming is most common today. In principle, this involves manual programming, that is to say the robot is taught its pattern of movements step by step. Attempts are now being made to reduce the "in-place" programming time as much as possible.

Figure 7.1 Programming of industrial robots: on-line or off-line

Key:

1. Programming method	7. Running a web
2. Manual method	8. Direct method of axes through manipulation; input of technological data
3. Setting [illegible] points, encoding the program sequence	9. Textual methods
4. Learning method	10. Description of the operating sequence by means of language
5. Startup and storage	
6. Method of axes and input of program sequence via programming equipment	



This takes place through development of more advanced programming languages. So-called off-line programming means that the program is developed separately from the robot. By so doing, the robot can be more effectively utilized. The goal is later to utilize CAD/CAM systems directly for optimum off-line programming. This is now being developed by West German control system manufacturers in cooperation with research institutes and advanced schools. The Reis company in Obernburg offers, for example, a simpler program for off-line programming of Reis robots. The additional cost will then be DM 8,000-10,000.

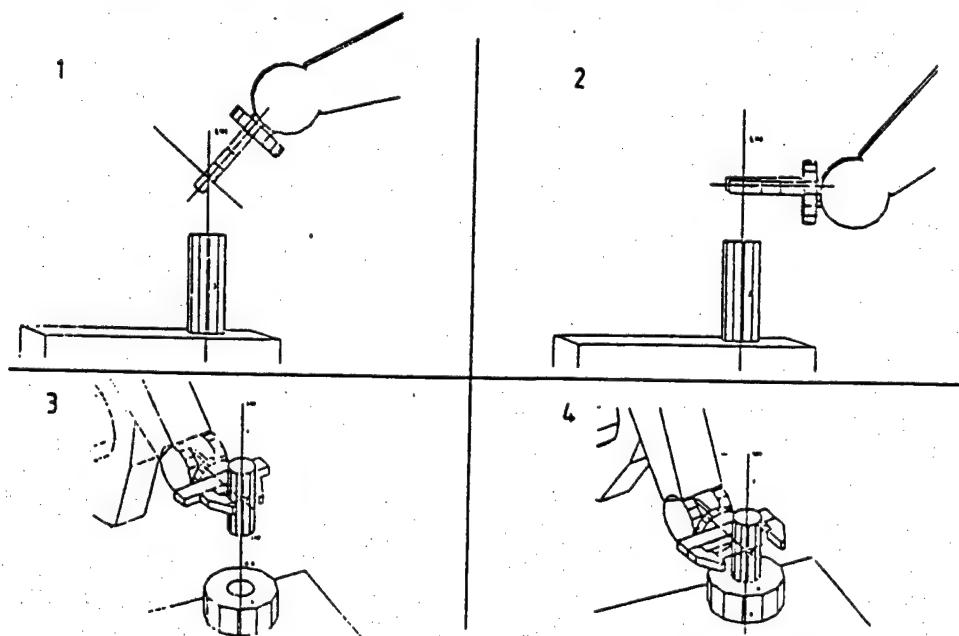
Better programs for error-finding (so-called debugger) are also important for avoiding unnecessary waste of time.

#### CAP (Computer Aided Planning)

System planning is very time-consuming for complex installations. The trend is now to simulate all movements and work cycles between the robot and the peripheral equipment on a screen, see Fig. 7.2. This type of system planning (CAP) then results in great savings of time. A CAD system is used in modelling as well. With the help of the computer all movements are optimized and collisions avoided.

Various systems are under development and testing in the FRG. The current problems of this method lie, among other things, with the design of the fine geometry in the area of work piece/gripping arm (6).

Figure 7.2 Graphic simulation and optimization of robot movements on a screen



## Mechanical/Dynamic Performance Characteristics

High movement speeds are needed in order to obtain short work cycles in a robot system. In order to cope with these while retaining accuracy, improved static and dynamic performance characteristics are required. The servo systems must be capable of varying inertial moments for various loads and positions. Certain strong fiber plastics are expected to achieve increased application for construction of movable robot parts, whereby the load capacity increases in comparison with the robot's own weight.

Further, adaptively regulated gripping tools are needed for correct and sure handling of varying details.

Research in these various areas is conducted among other places at the Fraunhofer Institute for Production Facilities and Construction Technique (IPK) in Berlin. Fig. 7.3 shows a theory example from IPK (3).

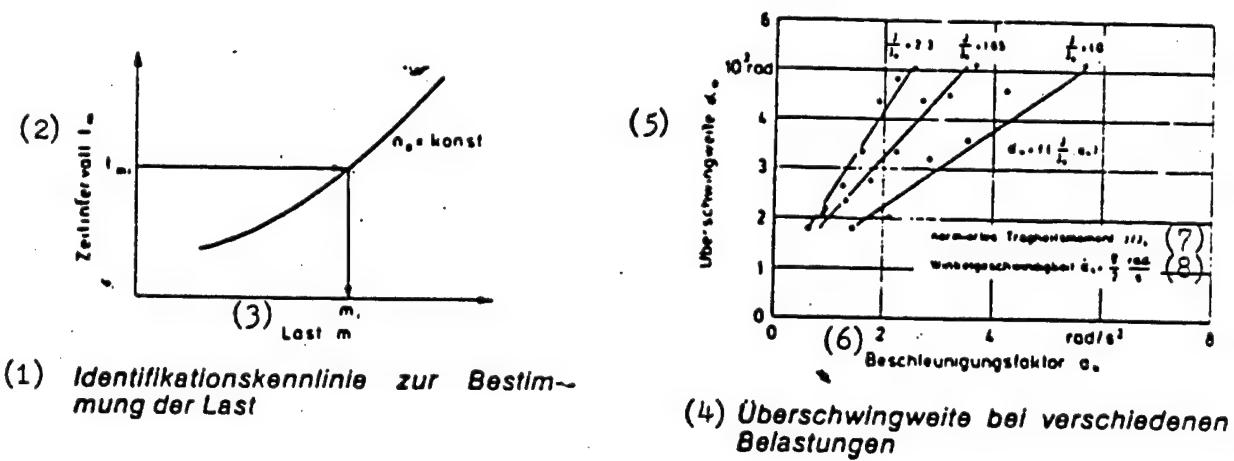


Figure 7.3 IPK study of load identification and calculation of the oscillation of each. After identifying the load, an adaptive regulation takes place for limitation of the oscillations occurring during optimal acceleration of the robot part.

Key: 1. Characteristic curve for determining the load 2. Time interval 3. Load 4. Overshoot for various loads 5. Overshoot 6. Acceleration factor 7. Standardized inertia moment 8. Angle speed

A prognosis for various future trade sectors for industrial robots in the FRG has been presented by the Kuka robot company in Augsburg, see Fig. 7.4. Here, the automobile industry and electrotechnical/electronic industry dominate the market in 1990.

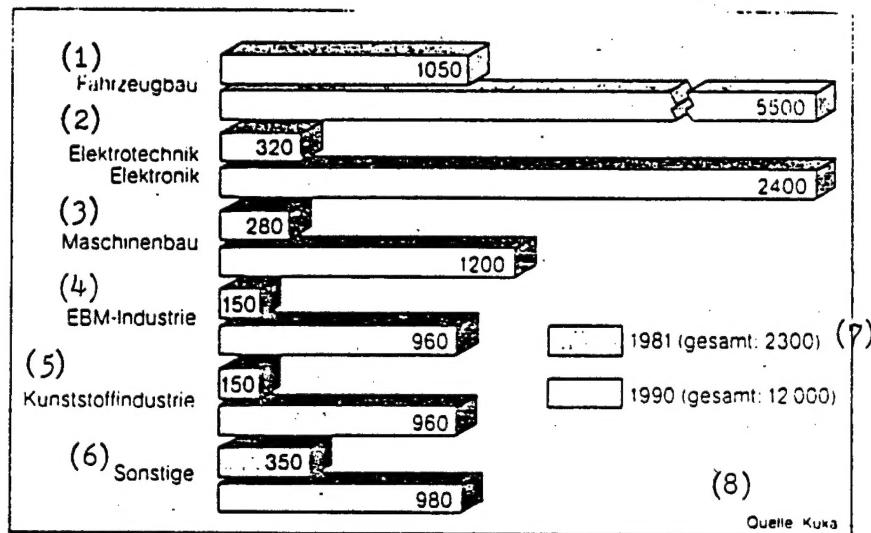


Fig. 7.4 Prognosis for future trade sectors for industrial robots in the FRG

Key:

1. Vehicle construction
2. Electrotechnology/Electronics
3. Machine-building
4. Iron, sheetmetal and metal-processing industry
5. Synthetic materials industry
6. Other
7. 1981 (total: 2,300) 1990 (total: 12,000)
8. Source: Kuka

For the future development and application of industrial robots it is important that the focus is on the human being. Social problems can prevent and delay technology. It is the human who is to control the machine and not the reverse.

If worst comes to worst, an emergency shutdown has to be employed!

## FIGURE CAPTIONS

Fig. 3.7 The VW robot mounts the car battery in Hall 54

Fig. 3.8 The spare tire is put into place by Robbie the Robot in Hall 54

Fig. 4.3 Gripping claw for industrial robots developed at the Fraunhofer Institute in Stuttgart.

Fig. 4.6 Siemens optical Videomat vision system. The video camera is used for identification of details with complex form and different positions.

Fig. 4.7 Evaluation of image information with Siemens Videomat vision system.

Fig. 4.12 Binary image of the welding seam with positions indicated. The vertical white line corresponds to the welding seam, the dotted vertical lines indicate the welding electrode position.

Fig. 5.1 A "stripped" VW robot crammed with mechanical elements and electric motors.

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